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Journal of Magnetism and Magnetic Materials 305 (2006) 16–23

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

Characterization of heat-assisted magnetic probe recording on CoNi/Pt multilayers

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Received 28 July 2005; received in revised form 3 November 2005
Available online 9 December 2005

Abstract

A method of heat-assisted magnetic recording (HAMR) potentially suitable for probe-based storage systems is characterized. In this work, field emission current from a scanning tunneling microscope (STM) tip is used as the heating source. Pulse voltages of 2–7 V were applied to a CoNi/Pt multilayered film fabricated on either bare silicon or oxidized silicon substrates. Different types of Ir/Pt and W STM tips were used in the experiment. The results show that thermally recorded magnetic marks are formed with a nearly uniform mark size of 170 nm on the film fabricated on bare silicon substrate when the pulse voltage is above a threshold voltage. The mark size becomes 260 nm when they are written on the identical film fabricated on an oxidized silicon substrate. The threshold voltage depends on the material work function of the tip, with W having a threshold voltage about 1 V lower than Pt. A synthesized model, which contains the calculation of the emission current, the simulation of heat transfer during heating, and the study of magnetic domain formation, was introduced to explain experimental results. The simulation agrees well with the experiments.

Keywords: High-density perpendicular recording; Heat-assisted magnetic recording (HAMR); Scanning tunneling microscope; Probe recording

1. Introduction

The super-paramagnetic effect which induces the thermal relaxation of recorded information [1] is the fundamental obstacle to increasing magnetic recording density. To achieve thermal stability of recorded information, increases in the coercivity and anisotropy of the recording medium are needed. This makes traditional recording more difficult because conventional heads cannot generate sufficient field to switch the magnetization of the bits in thermally stable media. To overcome this obstacle, heat-assisted magnetic recording (HAMR), has been proposed [2]. HAMR draws on concepts from traditional magneto-optical (MO) recording for the writing process, but is not restricted to optical read-back.

In addition to optical heating methods suggested by extensions of MO recording, another possible approach to HAMR is the use of field emission current from a sharp metallic tip for heating. This has the possibility of very high spatial resolution as scanning tunneling microscopes (STMs), which have similar architectures, show atomic resolution in surface observation [3–5]. Nakamura et al. [6] demonstrated this writing method with an STM several years ago, and saw a mark size that increased with increasing tip voltage. We have also demonstrated the process previously [7], but saw very little dependence of mark size on tip voltage above a certain writing threshold. In this work, we performed similar experiments on an alternate medium and built a synthesized model of the writing process that quantitatively explains the writing threshold voltage and the mark size insensitivity to applied voltages.

2. Experiments

2.1. Medium and experimental setup

The recording medium in our work is a CoNi/Pt multilayered film. It consists of 20 repeats of 0.55 nm-$Co_{50}Ni_{50}$

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0304-8853/$ - see front matter
doi:10.1016/j.jmmm.2005.11.022

and 0.87 nm-Pt bilayers, yielding a total film thickness of about 28 nm. The multilayers are sputtered on two kinds of substrates simultaneously: a bare silicon substrate and an oxidized silicon substrate. The thickness of the oxidization layer is about 400 nm. There is a 23-nm-thick Pt seed layer between the film and the substrate. The Argon pressure in the sputter chamber is 1.6×10^{-2} mbar and the back-pressure is less than 5×10^{-8} mbar. We measure its anisotropy in perpendicular orientation $K_u = 2.5\times10^5\,J/m^3$, saturation magnetization $M_S = 3.4\times10^5\,A/m$, coercivity $H_C = 1.1\times10^5\,A/m$ (or 1.4 kOe) and nucleation field $H_n = 4.3\times10^5\,A/m$ at room temperature in a vibrating sample magnetometer (VSM). The M–H loop of this medium is shown in Fig. 1. From the figure we find that the "appearing" nucleation field H'_n is very close to the coercivity H_C. However, the actual nucleation field should be the sum of H'_n and the demagnetizing field H_D generated by the medium itself, which is equivalent to the saturation magnetization M_S. The Curie temperature of the film is about 250 °C. The temperature-dependent property of magnetic parameters (like H_C, M_S, K_u, and H_n) is also measured by VSM at elevated temperatures. All of them show a linear dependency to the temperature from room to Curie point.

A Digital Instruments Dimension 3000 scanning probe microscope (SPM) was used for writing and imaging. Atomic force microscopy (AFM) mode was applied to scan the topographic features of the film, and magnetic force microscopy (MFM) mode was used to image the magnetic domain structures. STM was used for thermal writing. In this work, two types of STM tips are used: one Ir/Pt alloy, and the other W. During STM scanning, the tip-sample junction is held at a bias voltage of 100 mV and a set point current of 2 nA, from which the tip-sample spacing is estimated to be 0.7 nm during scanning [8]. The film is heated locally by applying pulses of 2–7 V in amplitude and 500 ns in duration, with a rise time of 100 ns to the sample. Short pulses prevent the position feedback system (BW = 15 kHz) from reacting to the increased current and withdrawing the tip [7].

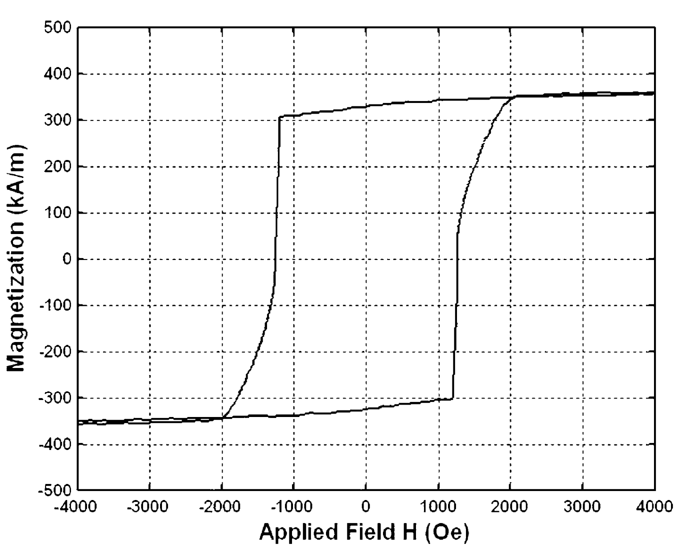

Fig. 1. M–H loop of CoNi/Pt multilayered film, measured in VSM.

The addition of external magnetic field is very important in HAMR work [2]. However, it is not the focused point that is examined in this paper. When written marks were isolated with a distance greater than five times the mark diameter, the demagnetizing field from its neighborhood will be enough to switch the magnetization during heating. In this case, the external field is not necessary. We will explain it in detail in this paper. The study of the effects of an external magnetic field on thermo-magnetic writing will be published elsewhere.

2.2. *Basic results: writing marks on medium (silicon substrate) by Ir/Pt tip*

Some sample marks are shown in Fig. 2. Those marks were written by Ir/Pt tip, and on the film fabricated on bare silicon substrate. The mark size is determined as the full-width half-maximum (FWHM) of the MFM signal. Similar to our previous work [7], those written marks are magnetic in nature and the writing is reversible.

An important task in my work is to examine the dependence of mark size on bias voltage and other parameters. In this section, marks were written by an Ir/Pt tip on the film fabricated on a bare silicon substrate. Fig. 3 shows the plots of average mark size and the rate of successful writing as a function of pulse voltage. In the figure, the upper plot shows the average mark diameter as a function of applied pulse voltage. In this plot, the average value of mark size is based on the average of observed marks. Failed writing was not counted. In the experiment of thermal writing, some marks were missing even when a pulse voltage was applied there. In order to capture these statistics, another plot was displayed below the former one in Fig. 3, to show the rate of successful writing by a single voltage. We observe a threshold voltage of writing at 4 V. Below 4 V, no marks were observed; above 4 V, mark size increases slightly with increasing bias voltage. The average mark size is about 170 nm.

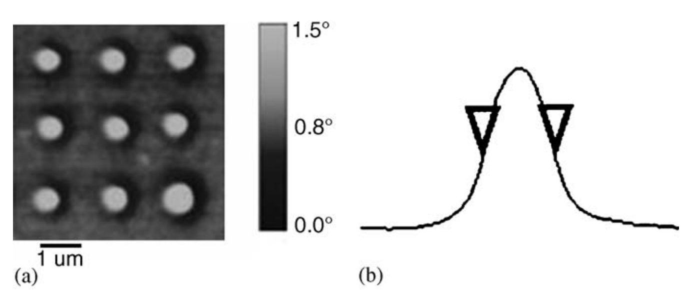

Fig. 2. MFM image of marks: (a) MFM image of marks made by 6 V pulses, Ir/Pt STM tip and (b) mark size is measured by the FWHM of the MFM signal.